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(56), (58) (continued overleaf)

(54) **Production of superalloy sheet**

(57) A nickel-chromium or nickel-cobalt-chromium base superalloy in which the content of hardening elements is such that the value of the hardener factor

$\frac{1}{2}(\%Mo + \%W + \%Nb + \%Ta + \%Hf) + (\%V + \%Ti + 2\%Al)$

is from 15.5 to 25% is formed into sheet by consolidating powder of the alloy into a bar by means including extrusion and hot rolling the bar to sheet in a direction transverse to the direction of extrusion.

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## SPECIFICATION

## Production of superalloy sheet

- 5 This invention relates to the production of sheet of nickel-chromium and nickel-cobalt-chromium based superalloys, and to the production of articles and parts therefrom. 5

The name superalloy is commonly given to alloys used for articles and parts that are subjected in service to high stress at elevated temperatures for long periods of time, and therefore require a combination of high stress rupture strength and resistance to creep at high temperature.

- 10 As the content of hardening and strengthening elements such as molybdenum, tungsten, niobium, tantalum, hafnium, vanadium, titanium and aluminium used to confer these properties is increased to the levels required by modern gas-turbine engine design, it becomes more and more difficult to obtain a homogeneous structure and freedom from segregation in the alloys in the cast form. They are therefore increasingly being made by consolidating pre-alloyed powder 10
- 15 of the desired composition by hot isostatic pressing and/or extrusion, followed by hot and cold-rolling to sheet or other forms. 15

The presence of the hardening elements in large amounts necessarily also makes the alloys difficult to hot-work, and particularly to hot-roll. Thus we find that if the total content of hardening elements is too high, attempts to work bar extruded from pre-alloyed powder to sheet by hot-rolling in the direction of extrusion (so-called straight rolling) result in such extensive cracking that the yield of usable product is unacceptably small. 20

- We have now surprisingly found that the incidence of cracking in the hot-rolling of such bar having a high content of hardening elements is greatly reduced if, contrary to normal practice, the bar is cross-rolled, i.e. rolled transverse to the direction of extrusion. When this is done, cracking at the ends of the extruded bar may also be controlled, and often eliminated, by "buttering" these ends with a deposit of a suitable metal or alloy before cross-rolling. 25

- Generally speaking, the cross-rolling procedure of the invention is useful for alloys having a total content of hardening elements such that the "hardener factor"  $\frac{1}{2} (\%Mo + \%W + \%Nb + \%Ta + \%Hf) + (\%V + \%Ti + 2\%Al)$  is from 15.5 to 25%, more particularly 17 to 23% or preferably 18 to 22%. 30

Broad and preferred ranges of alloy compositions that may be used (subject to their hardener factors being within the ranges set forth above) are set out in Table I.

TABLE I

35 Composition ranges (wt.%) 35

	Broad	Preferred	
Cr	2-20	6-17	
40 Co	0-25	5-20	40
Mo	0-20	0-15	
W	0-20	0-15	
Nb	0-5	0-2	
Ta	0-10	0-5	
45 V	0-5	0-2	45
Hf	0-5	0-3	
Ti	0-10	1-6	
Al	2-10	3-8	
Zr	0-1	0-0.2	
50 B	0-1	0-0.85	50
C	0-1	0-0.2	
Y + Ce + La	0-1	0-0.2	
Ni and impurities	Balance	Balance	
55	(Ni + Co > 55%)	(Ni + Co > 55%)	55

- To illustrate the invention, pre-alloyed powders of the two Alloys A and B having the contents set forth in Table II were produced by argon atmosphere. The powder of Alloy A had a particle size of less than 150  $\mu m$ , and 84% by weight of the powder of alloy B was also less than 150  $\mu m$  and the whole of it was less than 250  $\mu m$ . Powder of each alloy was placed in deep drawn mild steel cans 54 mm outside diameter, 100 mm long and 2.5 mm wall thickness which were evacuated at 300°C, sealed, and extruded to bar approximately 15.5  $\times$  7.6 mm section to consolidate the alloy. In each case the predetermined optimum extrusion temperature was used, namely 1120°C for alloy A and 1200°C for alloy B. 60

- 65 The bar was then cut into lengths (76 mm except where otherwise specified) and subjected 65

to hot-rolling at a roll surface speed of 40 m/min, using the predetermined optimum hot-rolling temperature of 1080°C for alloy A and 1130°C for alloy B.

It was found that the extended bar of alloy A could be hot rolled by straight rolling in one pass using a roll gap of 0.75 mm from a thickness of 7.6 mm down to 1.20 mm (an 84% reduction) with no edge cracking and only slight front end cracking. Thus hot rolled strip or sheet of alloy A, which had a hardener factor of 14.11%, could be produced by straight rolling.

Attempts to hot-roll the extruded bar of alloy B (hardener factor 19.53%) by straight rolling in a similar manner were unsuccessful. With a roll gap of 1.0 mm the bar split assunder, and even with a roll gap of 3.0 mm it suffered severe edge cracking and split up to half the length of the sample. Even the use of successive passes in which the roll gap was reduced from an initial value of 7.0 mm by 0.5 mm per pass, with reheating between passes, gave unacceptable edge cracking even when the thickness had only been reduced to 6.0 mm (a reduction of 21% from the initial thickness of 7.6 mm).

In contrast to these unsatisfactory results with alloy B, cross-rolling of portions of the extruded bar 76 mm, 127 mm, and even 254 mm long at 1130°C with a roll gap of 2.0 mm and even 1.5 mm resulted in little or no cracking along the long edges of the bar, where hopelessly bad cracking had occurred in the straight rolling tests. Reductions of 72% were thus obtained with bar 7.6 mm long and of 60–64% with portions 127 mm long. Some end cracking occurred, but this was largely eliminated by “buttering” the ends of the portions of extruded bar with a weld deposit of nickel or a 72 Ni-20 Cr-3 Mn-Nb alloy.

It is not clear whether these weld deposits act by a purely mechanical effect, or by avoiding cooling of the ends of the bar.

All the hot rolling operations described above were carried out without removal of the mild steel can from the surface of the extruded bar. This is believed to be beneficial by avoid chilling of the surface of the superalloy by the surface of the rolls or assisting mechanically or by lubrication.

Another alloy to which the cross-rolling procedure of the invention may usefully be applied is Alloy C in Table II.

The production of sheet of Ni-Cr and NiCoCr based superalloys by extrusion of prealloyed powder and cross-rolling the extruded bar according to the invention is particularly useful as a step in the production of the so-called wafer blades for gas turbine engines. These blades are described for example by R E Anderson et al in a paper entitled “Use of RSR alloys for High Performance Turbine Air Foils” published in the Proceedings of the Second Conference on Rapidly Solidified Materials, held at Reston, Virginia in March, 1980. In the production of such blades a stack of sheets of

TABLE II

ALLOY COMPOSITION

Alloy	Weight percent, balance nickel												Factor
	Cr	Co	Mo	W	V	Ta	Hf	Ti	Al	Zr	B	C	
A	Anal.	14.8	16.8	5.02	-	-	-	3.6	4.0	0.045	0.021	0.024	14.11
	Max.	16	19	5.3	-	-	-	3.7	4.3	0.08	0.03	0.04	14.95
	Min.	14	16	4.8	-	-	-	3.3	3.8	0.02	0.01	0.02	13.30
B	Anal.	8.9	9.9	0.01	-	2.6	1.6	1.45	5.5	0.06	0.025	0.15	19.53
	Max.	10	11	1	-	3.0	1.8	1.7	5.7	0.08	0.03	0.18	21.65
	Min.	8	9	0	-	2.3	1.2	1.3	5.3	0.02	0.01	0.02	18.15
C	Nom.	10	15	3	0.85	-	-	4.8	5.5	0.05	0.015	0.18	18.15
	Max.	11	17	3.3	1.0	-	-	5.0	5.7	0.08	0.02	0.20	19.05
	Min.	9	13	2.8	0.7	-	-	4.6	5.3	0.02	0.01	0.02	17.40

$$\text{Factor} = \frac{\text{Mo} + \text{W} + \text{Nb} + \text{Ta} + \text{Hf}}{2} + \text{V} + \text{Ti} + 2\text{Al}$$

superalloy having channels etched in their surfaces which cooperate to form cooling passages in the finished blade is bonded, e.g. by diffusion bonding, to form a block from which a blade is machined.

- 5 It is advantageous to subject the sheets or wafers to directional recrystallisation either before  
or after assembling to give an aligned grain structure, and for this purpose the hot-rolled sheet  
may first be further reduced in thickness by cold-rolling using the procedure described in GB-A-2  
110 241. This procedure comprises successively cold rolling the sheet in two directions at  
rights angles to one another to effect a total reduction of thickness of greater than 50% and  
with a ratio of the reductions in the first and second cold rolling being from 70:30 to 80:20.  
10 The sheets are then heated, either before or after assembly into the block, to effect directional  
recrystallisation. For this purpose it is an advantage of Alloy B sheet prepared by the process of  
the invention that it has a gamma—solvus temperature of 1245–1250°C but does not liquate  
below 1280°C, so that it can be heated within this temperature range for recrystallisation.

#### 15 CLAIMS

1. Process of producing sheet of an alloy containing from 2 to 20% chromium, from 2 to  
10% aluminium, 0 to 25% cobalt, 0 to 20% molybdenum, 0 to 20% tungsten, 0 to 5%  
niobium, 0 to 10% tantalum, 0 to 5% vanadium, 0 to 5% hafnium, 0 to 10% titanium, 0 to  
1% zirconium, 0 to 1% boron, 0 to 1% carbon and 0 to 1% in all of yttrium, cerium and  
20 lanthanum, the balance, apart from impurities, being nickel in an amount such that the total  
content of nickel and cobalt is at least 55%, wherein the content of the elements Mo, W, Nb,  
Ta, Hf, V, Ti and Al is such that the value of the hardener factor  
 $\frac{1}{2}(\%Mo + \%W + \%Nb + \%Ta + \%Hf) + (\%V + \%Ti + 2\%Al)$  is from 15.5 to 25%, which  
comprises consolidating powder of the alloy into a bar by means including extrusion and rolling  
25 the bar to sheet in a direction transverse to the direction of extrusion.